Comparison of intrarenal pressure between convention and vacuum assisted ureteral access sheath using an Ex-vivo porcine kidney model

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Abstract:

Objective:

To prove the vacuum assisted ureteral access sheath (vaUAS) is more effective in maintaining a lower IRP than conventional ureteral access sheath (cUAS).

Materials and methods:

The model consisted of 12 freshly harvested adult porcine kidneys. Either a 12/14F cUAS or vaUAS was alternately inserted into the ureter to one cm below the renal pelvis. Upper, middle, and lower calyces were punctured, and 6F pressure monitor catheters were introduced. IRP with cUAS was monitored using various irrigation rates. IRP with vaUAS was monitored with the same irrigation rates; various aspiration pressures; and vent fully closed, 50% closed, and fully open.

Result:

cUAS with irrigation rate of 50 c.c./min. resulted in IRP < 30 mmHg. 50 to 100 c.c./min. should be used with caution. When irrigation rate exceeded 100 c.c./min., IRP rose to ≥30 mmHg in most instances. With vent closed, vaUAS with with vacuum pressure ≥150 mmHg and irrigation rate of 50 c.c., 100 c.c., and 150 c.c./min. generally resulted in IRPs <5 mmHg. With vent half-closed, vaUAS with vacuum pressure ≥300 mmHg and irrigation rate of ≤ 100 c.c./min. avoided IRP >30 mmHg. vaUAS with vent open showed limited advantages over cUAS.

Conclusion: vaUAS maintains lower IRP than cUAS under same parameters. Both vaUAS and cUAS can be used when irrigation is ≤ 50 c.c./min. vaUAS showed clear advantages over cUAS in maintaining lower pressure when irrigation rate is ≥ 100 c.c/min.

(234 words)

Key Words: Intrarenal pressure, Porcine kidney, Ureteral access sheath

Introduction:

Retrograde intrarenal surgery (RIRS) using flexible ureteroscope (fURS) has become a common urological procedure. It is indicated for the treatment of renal stones less than two centimeters in size that either failed or are not suitable for extracorporeal shock wave lithotripsy, according to the AUA and EAU guidelines[1,2]. RIRS requires irrigation to allow visualization. Irrigation will result

in increased intrarenal pressure (IRP). Hinman[4] and other studies[5,6] demonstrated that IRP greater than 30 to 35 mmHg (41 to 48 cmH_2O) could result in pyelo-renal backflow with deleterious consequences. Subsequent research has shown that pyelo-renal backflow could occur at an even lower pressure of 10-20 mmHg[7,8]. Thus, high IRP is a major concern in the RIRS. Ureteral access sheath (UAS) is often used in RIRS. There are two types of UAS: the conventional UAS (cUAS) and the vacuum assisted UAS (vaUAS). The cUAS is a straight tube (Fig. 1-A). It acts as conduit for the insertion and extraction of URS and for passive egress of the irrigation fluid. vaUAS differs in that it has a 65 mm oblique side branch that can be connected to a vacuum machine (Fig. 1-B). There is a 14 mm longitudinal vent on this side branch to allow the operator to adjust the vacuum pressure (Fig. 1-C). The vent is located approximately 20 mm from the connecting end of the side branch. The vaUAS, with its ability to allow continuous negative pressure aspiration, was perceived to be able to maintain a lower IRP than the cUAS during RIRS. However, there is no study to confirm this hypothesis. It is difficult to monitor the IRP in patients during RIRS. The only reliable measurement was in patients who already had nephrostomy tubes in place. Even in this scenario, the IRP could only be measured around the nephrostomy tube. We decided to create an ex-vivo porcine kidney model to study the IRP in vitro using these two types of UAS. We learned several lessons in developing this kidney model. The first time, we contracted the slaughterhouse to provide us with several porcine kidneys. None of the kidneys was found to be useful. The ureters were cut too short. Often, either the renal capsules and/or renal pelvises were damaged. The second time, we procured the kidneys ourselves. We preserved the kidneys in the freezer for the experiments later. To our chagrin, we found that freezing and thawing changed the elasticity of the renal tissue, making the kidneys unsuitable for the experiments. The ureters and renal pelvises became friable and easily torn. Furthermore, the renal tissue would not seal around the puncture needle, resulting in fluid leaking freely around it; this rendered pressure measurement unreliable. Finally, we learned that trans-renal puncture using fluoroscopic guide was quite difficult. The porcine calyces were numerous, and often the infundibula were narrow. It was hard to identify the calyx that we intended to puncture. The easiest way to achieve a successful puncture was to identify the appropriate calyx using fURS, then turn off the lights in the laboratory and puncture directly toward the light. The needle could be seen entering the calyx.

We submitted our study protocol to and obtained approval from our Institutional Ethic Committee.

2.1 The porcine kidney model

We procured the experimental porcine kidneys ourselves directly from the slaughterhouse. The pigs are generally slaughtered starting at midnight for the market in the morning. The slaughterhouse processes the pigs in an assembly line fashion. The animals were instantly killed using a high voltage stunt gun. The carcasses were then hung upside down by the hind legs on a conveyor belt. They were decapitated first and then blood drained. A worker cut open the abdomen, including the pubic symphysis, with a midline incision. The intestines would fall out at this point; the kidneys and the ureters were exposed. With assistants spreading open the abdominal wound, we harvested the kidneys and ureters with enbloc dissection, similar to radical nephroureterectomy. Care was taken to remove generous amount of perinephric and periureteric fat and to preserve the renal pelvis. The ureters were transected near their entrances into the bladder. The kidneys were preserved in cooled normal saline and transported in a cooler. We started our experiment the next morning. Each fresh porcine kidney was placed on a pegboard and secured with thumb tacks. Excessive perirenal and periureteric fat were trimmed, but the capsule was preserved. Either a 12/14 Fr. vaUAS (ClearPetra, Guangzhou Wellead Medical, China) or cUAS (Wellead Medical China) was inserted over a guidewire. The sheath was advanced to about one centimeter below the renal pelvis. The obturator was removed and the location of the distal end of the sheath was marked. The distal end could be easily seen and palpated through the ureter. It was also confirmed fluoroscopically. The sheath was secured to the distal end of the ureter using a 2-0 silk tie. A SemiFlex fURS (MaxiFlex, U. S. A) was used for this experiment. The tip of the scope is 7.8 Fr. or 2.6 mm in diameter; the base diameter is 9.6 Fr. or 3.2 mm in diameter; the working channel is 3.3 Fr.; and the working length is 65 cm. There was approximately 36% or 1.44π mm^2 difference in surface area between the sheath and scope. This would be the space for the egress of irrigation fluid. The scope was advanced into the pyelocalyceal system. Upper, middle, and lower pole calyces were identified and confirmed with fluoroscopy. The mid-calyces were generally very short and very close to the renal pelvis. Thus, we felt that the pressure in the renal pelvis and mid-calyces could be measured as one entity. Renal puncture was performed using the technique of aiming toward the light (Fig. 2). After seeing and positioning the puncture needle, a guide wire was inserted through the shaft of the needle. A 6Fr. tapered open-end

catheter was inserted into the punctured calyx. The guide wire was withdrawn. The catheter was connected to a pressure-measuring transducer (IntelliVue, Philips, Netherland). Instant glue, a Superglue equivalent (502 glue, China), was applied around the puncture site to ensure sealing of the puncture. Next, a retrograde pyelogram was performed. This was to confirm the position of the catheter and to check for any leakage around the puncture. We had not noticed any leakage around the puncture sites among the freshly harvested kidneys. The pressure transducer was leveled with the kidney. The tubing was primed and zeroed to commence the experiment. After completing experiment with this catheter and before the next puncture, the catheter was left in place and the end capped. This process was repeated after each puncture. The transducer was re-primed and re-zeroed after each pressure measurement.

2.1 Material:

12 adult hybrid Landrace porcine kidneys with mean length of 13.3 cm (range 12-14 cm) were successfully prepared for the experiment.

2.2 Method

After placement of each pressure-measuring catheter, 50 cc, 100 cc, and 150 cc of irrigation fluid were delivered through the working channel of the fURS through a constant flow rate irrigation pump (WANPump, Guangzhou Wellead, China). The flow pressures were 60, 90, and 220 mmHg respectively. When vaUAS was used, the vacuum pressure was set at 150, 300, and 450 mmHg with a portable suction machine (Yuwell, China). The IRP generally rose steadily with the irrigation and plateaued around 60 seconds. When the peak pressure was reached and fluctuated between 1- to 3-mm Hg, the highest number was recorded. We set 35 mmHg as the upper limit. When the IRP reached 35 mmHg and fluctuated between 35-37 mmHg or continued to rise beyond 37 mmHg, we would turn off the irrigation and record the pressure as 37 mm for statistical analysis purposes. This was the maximum pressure allowed for the experiment to avoid unintentional damage to the working model. Each kidney was punctured three times for upper, middle, and lower calyces. The pressure of each calyx was measured 30 times. The cVAS sheath was measured with flow rate at 50, 100, and 150 cc. The vaUAS sheath was measured with the same flow rates but with a vacuum pressure set at 150, 300, and 450 mmHg and with the vent fully occluded, 50% occluded, and completely open. To be accurate in occluding the vent, we marked the vent at the midpoint. A silicone tube (3 cm long and 9 mm in inside diameter) was split longitudinally on one side,

forming a casing. The casing was then used to cover the vent either completely or at the mid-point. To avoid any error or bias, we alternated UAS type, using the vaUAS first in one experiment, then the cUAS first in the next experiment.

2.3 Statistical analysis

All variables are expressed as means ±SD. We used Wilcoxon Rank Sum Test to perform both intragroup and intergroup analysis due to the non-normal distribution of variances. *P* value < 0.05 was deemed statistically significant. SPSS version 22.0 software was used for this analysis.

Results:

12 renal units were successfully procured and prepared for the study. We made 12 successful middle and lower calyceal system punctures. We failed to access the upper calyces in one unit. This was likely due to the extreme angle of this calyceal system. The results of the study are displayed in Tables 1 and 2.

In the intragroup analysis, we found no statistical differences in calyceal pressure between each of the porcine models under the same testing parameters; all had $P>0.05$. We also found no significant differences between the upper, middle, and lower calyceal pressures in all the porcine models; $P>0.05$.

In the intergroup analysis, there were no significant IRP differences using vaUAS with vent closed among different irrigation rates or vacuum pressures. However, as shown in Table 3, the IRP was significantly lower in vaUAS with vent closed than in cUAS. In vaUAS with the vent half-open, at 50 cc irrigation rate, the IRP was significantly lower than in cUAS under all three vacuum pressures; $P=0.005$. Also, in vaUAS with the vent half-open, at 100 cc irrigation rate and vacuum pressure of 300 mmHg and 450 mm Hg, the IRP was significantly lower than it was at the same irrigation rate in cUAS. There were only minor differences between vaUAS with vent open and cUAS.

Discussion:

According to extensive research[9-27], high IRP is an important issue, especially during RIRS with UAS. We extrapolated that our data should be applicable to any sheath and scope where the egress space is 36% or less. In this scenario, irrigation rate under 50 c.c./min. can be used safely with cUAS. More than 50 c.c./min. should be used with caution. Irrigation rate should not exceed 100 c.c./min. in most

instances. At 50 c.c./min. irrigation rate, vaUAS can maintain a low pressure with the pressure control vent either closed, partially closed, or open. However, for 100 c.c./min. flow rate, the vent should only be closed or partially closed. The only safe mode for irrigation rate at 150 c.c./min. is with the vent closed. We felt the optimal vacuum pressure was 300 mmHg. 450 mmHg vacuum pressure occasionally resulted in the renal pelvis collapsing at the opening of the sheath, especially at a lower irrigation rate. This could result in a negative IRP. In a clinical setting, it might compromise vision. We did not see any significant pressure differences between the upper, middle, and lower calyces under the same parameters. In our experiment, we could clearly see renal swelling and perirenal edema when IRP was consistently greater than 35 mmHg.

IRP is difficult if not impossible to assess during RIRS. Only three prior studies attempted to measure IRP during live RIRS[17,18,19]. One was done through retrograde pressure-measuring catheter[19]. Two were performed through previously inserted nephrostomy tubes[17,18]. These patients required emergent placement of nephrostomy tubes for various reasons, mostly for obstructing stones associated with sepsis or severe hydronephrosis; thus, were not entirely normal kidneys.

Both in-vivo and ex-vivo porcine kidneys had been previously used by others for pyelorenal backflow and IRP studies[20-23, 26]. Eight prior studies measured IRP with ureteral access sheaths [13-16,22,23,25,26]; three of them used porcine kidneys [22,23, 26]. Our study is the first using an ex-vivo porcine kidney to measure and compare IRP with retrograde infusion of irrigation fluid through fURS in two different functional sheaths. We recommend that surgeons be vigilant about high IRP during RIRS.

One limitation of this study is that this is an ex-vivo study; the IRP values might not be transferrable to an in-vivo setting. Also, due to the structural differences of the pyelocalyceal system, the porcine IRP might not be the same as the human IRP.

Conclusion: Our ex-vivo porcine kidney model appears to be a valid tool for studying IRP in vitro. When the surface area between the UAS and fURS is less than 1.44π mm^2, the irrigation rate of 50 c.c./min. can be used safely with cUAS. More than 50 c.c./min. should be used with caution. Irrigation rate should not exceed 100 c.c./min. in most instances. On the other hand, vaUAS with vent closed can be safely used with irrigation rates of 50 c.c., 100 c.c., and 150 c.c./min. and with vacuum pressure ≥150 mmHg. With an irrigation rate of 100 c.c/min., the

vaUAS can be used with vent half-closed and vacuum pressure ≥300 mmHg. vaUAS with vent open showed limited advantages over cUAS.

(2217 words)

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Author's Contribution:

Haibo Xi: Designing the experiment and writing the manuscript

Dong Wang and Zhenyuan Han: Performing the experiments and writing the manuscript

Yudong Bi and Gang Ma: Data collection

Guibin Xu and Qianyi Hu: Data analysis

Conflict of interest:

The authors of this study disclose no conflicts of interest. There was no funded for this study.

Informed consent:

This research used commercially acquired animal parts (porcine kidneys). There was no live animal involved. This research was reviewed and approved by the Institutional Ethics Committees of all the institutions involved in this study.Not all institutions have Animals Care and Use Committee.

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Figure legends.

Fig 1: A. Conventional Ureteral Access Sheath

B. Vacuum Assisted Ureteral Access Sheath

C. Longitudinal Vent on the Oblique Branch